SIMULATION-BASED ANALYSIS OF TENSILE, COMPRESSIVE, FLEXURAL AND THERMAL BEHAVIOUR OF AL5052-H32

Submitted By

Md Naim Mallik	ME2102024195
Muhidul Islam	ME2102024098
KM Shah Nawauz	ME2102024199
Md. Suzon Mia	ME2102024141
Md. Kamal Hossain	ME2102024249



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Supervised By:

G M Ismail Hossain

Supervisor & Lecturer

Department of Mechanical Engineering

Sonargaon University (SU)

Dhaka-1205, Bangladesh

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CERTIFICATE OF RESEARCH

This is to certify that the research work titled ***"Simulation-based analysis of tensile, compressive, flexural and thermal behavior of Al5052-H32"*** Submitted by Md Naim Mallik (ME2102024195), Muhidul Islam (ME2102024098), KM Shah Nawauz (ME2102024199), Md Suzon Mia (ME2102024141), Md. Kamal Hossain (ME2102024249)" under the supervision of G M Ismail Hossain, Lecturer, Department of Mechanical Engineering, Sonargaon University, Dhaka, Bangladesh.

The findings presented in this thesis are based on genuine and authentic research conducted during the academic period (Jan 2023 – Jan 2025). The thesis does not contain Simulation previously published or written by another person, except where due acknowledgment has been made.

Furthermore, the work complies with the ethical standards and guidelines for research as set forth by ASME (American Society of Mechanical Engineering) and adheres to the best practices recommended by Dassault Systèmes Abaqus for simulation accuracy and integrity.

Supervisor

Name: **G M Ismail Hossain**
Designation: Lecturer
Signature: ……
Date:

Authors

Name: Md Naim Mallik
Signature: ……
Date:
Name: Muhidul Islam
Signature: ……
Date:
Name: KM Shah Nawauz
Signature: ……
Date:

Name: Md. Suzon Mia
Signature: ……
Date:
Name: Md. Kamal Hossain
Signature: ……
Date:

CANDIDATES DECLARATION

We are students of Sonargaon University solemnly declare this academic thesis titled ***"Simulation-based analysis of tensile, compressive, flexural and thermal behavior of Al5052-H32"***. All ideas, data, and analysis presented herein are the result of our independent research efforts. Any sources consulted for this thesis have been duly acknowledged and cited. We affirm that this thesis has not been submitted for any other degree or qualification at any other institution. We take full responsibility for the content and conclusions drawn in this thesis. Furthermore, we adhere to the academic integrity standards set forth by Sonargaon University, and any violations, therefore, would be subject to appropriate disciplinary action. We adhere to the academic integrity standards set forth by Sonargaon University, and any violations, therefore, would be subject to appropriate disciplinary action. We hereby declare that this simulation is our original work, and it has been written by candidates in its entirety.

We properly credited every single information source that we used to create the thesis.

Signature of Supervisor

……..……
(**G M Ismail Hossain**)
Supervisor & Lecturer
Department of Mechanical Engineering
Sonargaon University (SU)

Signature of Students

……..……
(Md Naim Mallik)

……..……
(Muhidul Islam)

……..……
(KM Shah Nawauz)

……..……
(Md. Suzon Mia)

……..……
(Md. Kamal Hossain)

CERTIFICATION OF APPROVAL

This thesis titled ***"Simulation-based analysis of tensile, compressive, flexural and thermal behavior of Al5052-H32".*** Submitted by Md Naim Mallik (ME2102024195), Muhidul Islam (ME2102024098), KM Shah Nawauz (ME2102024199), Md Suzon Mia (ME2102024141), Md. Kamal Hossain (ME2102024249) " has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of B.Sc. in the Department of Mechanical Engineering, Sonargaon University (SU), Dhaka, Bangladesh in January 2025.

Countersigned

……..

G M Ismail Hossain

Lecturer

Department of Mechanical Engineering

Sonargaon University (SU)

Dhaka-1205, Bangladesh

ACKWNOLWEGMENT

In the name of Allah, the Most Gracious, the Most Merciful. All praise and thanks are due to Allah alone, the Source of all knowledge and guidance, without whom this academic endeavor would not have been possible. We would like to convey our heartfelt thanks to the people and institutions who helped us complete this thesis, which has been finished at Sonargaon University and is titled ***"Simulation based analysis of Tensile, Compressive, Flexural and Thermal behavior of Al5052-H32"***. First and foremost, we express our sincere appreciation to our supervisor **G M Ismail Hossain,** for his invaluable guidance, unwavering support, and insightful feedback throughout this research. His expertise, encouragement, and friendly demeanor have been pivotal in shaping the direction of this study and enhancing its quality.

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[Authors]

Md Naim Mallik

Muhidul Islam

KM Shah Nawauz

Md Suzon Mia

Md Kamal Hossain

DEDICATION

This thesis is dedicated to our cherished parents and family, who have consistently provided us with motivation, support, and courage to pursue our further education and to confront life's unforeseen circumstances with fervor, thrills, and amazement of Allah.

Secondly, this thesis is done with deep pain and consistent unity to the innocent souls who perished, the uprooted families, and finally, the gallant people of Palestine who are suffering from genocidal oppression. All the children of war and all the parents who have to endure the loss of their children, but more importantly, every individual who is trying to exist in the decaying society.

This dedication is also a call to the global academic and scientific community to remember the human cost of silence and to use our platforms to advocate for justice, equality, and peace. We hope that this work, though menial in its scope, reverberate the values of truth and justice that every scholarly person is called to uphold. May it serve as a reminder of the importance of compassion and the shared responsibility we own as global citizen to endure against iniquity wherever it occurs.

In the name of humanity and the pursuit of peace, we dedicate this thesis to the people of Palestine.

ABSTRACT

In this project, the correlation between experimental data and simulation analysis to elucidate deformation behaviors and thermal stamping processes of engineered materials. The tensile, compressive, and flexural properties of aluminum alloy Al5052-H32 were assessed at strain rates from 0.001 to 2500 s^{-1}, aspect ratios of 0.5 and 1.5, and temperatures between 25°C and 450°C. Quasi-static and dynamic testing demonstrated the alloy's vulnerability to Portevin–Le Chatelier effects, with stress-strain curves indicating peak stresses reaching 291 MPa where minimum ultimate stress is 216 MPa in tensile tests. Fracture processes shifted from ductile to brittle at rising temperatures, as shown by simulation result of the fracture surface morphology. On the other hand, in compression test the lowest ultimate compression stress is 199 MPa and the maximum ultimate stress is 368 MPa, that increase rate is almost doubled. Furthermore, for flexural test where minimal ultimate stress is 399 MPa but peak ultimate stress is 401 MPa. Where deviation overall is less than 3% for this three test, it means simulation result is quite align with the experimental data. Experimental and finite element simulations were conducted to investigate thermal stamping methods for alloy sheets, which are crucial in aerospace and marine applications.

Heat flow markedly escalated with distance during thermal operations, reaching a maximum of 114186 W/m^2 at 450°C. Finite element models conducted using Abaqus accurately represented stress distribution, deformation patterns, and heat effects, demonstrating a strong connection with actual data. Statistical error analysis revealed disparities of nearly 2% for tensile and the Flexural simulations test, where compression test shown highest 2.51%. The results underscore the significance of precise simulation methods in accurately representing real-world material behaviors, enabling enhanced optimization of manufacturing processes. This study offers essential insights into the mechanical and thermal properties of materials, integrating experimental and computational methods for advanced applications in the aerospace and automotive sectors.

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NOMENCLATURE

Al5052-H32	Aluminum alloy used in the study, known for its corrosion resistance and strength-to-weight ratio.
FEM	Finite element method, a numerical simulation technique.
FEA	Finite element analysis, a computational technique for simulating material behaviors.
ASTM	American Society for Testing and Materials
SEM	Scanning electron microscopy, used for analyzing microstructures and fractures.
E(Young's Modulus)	Stiffness of the material, measured in MPa.
σ (Stress)	Force per unit area, measured in MPa or N/mm².
ε (Strain)	Deformation per unit length (dimensionless).
ν (Poisson's Ratio)	Ratio of transverse strain to axial strain (dimensionless).
μ	Friction Coefficient, Resistance to sliding between two surfaces.
τ	Shear Stress, Stress acting parallel to the surface, measured in MPa.
σy (Yield Stress)	Stress at which plastic deformation begins, measured in MPa.
UTS	Ultimate Tensile Strength, Maximum stress material can withstand before fracture, measured in MPa.
k	Thermal Conductivity, A measure of heat transfer through a material, measured in W/m·K.
CTE	Coefficient of Thermal Expansion, Material's expansion per degree temperature rise, measured in 1/°C.
AR	Aspect Ratio, Ratio of specimen height to diameter in compression tests.
Rσ	Stress Ratio, Ratio of applied stress to reference stress.
PL	Plastic Limit, Onset point of irreversible deformation.
PCL Effect	Portevin–Le Chatelier effect, associated with serrated flow during deformation.
q	Heat Flux, Heat transfer per unit area, measured in W/m².
ΔT	Change in Temperature, Difference in temperature across a material or system, measured in °C.
θ	Heat Transfer Angle, Directionality of heat movement in thermal analysis.
CF	Carbon Fiber, Common composite material studied in thermal stamping.
BC	Boundary Conditions, Constraints applied in simulations (e.g., fixed edges).
SBH	Split Hopkinson Bar
UTM	Universal Testing Machine
PE	Péclet Number
RE	Reynolds Number
MPa	Megapascals, unit of stress or pressure (N/mm²).
°C	Degrees Celsius, unit of temperature.
s^{-1}	Per second, unit for strain rate.
mm	Millimeters, unit of length.
N/mm²	Newton per square millimeter, another unit for stress (equivalent to MPa).

CHAPTER 1: INTRODUCTION

1.1 Overview

This study examines the stress-strain behavior and thermal conductivity of the aluminum alloy AL5052-H32 to further understanding of its thermal and mechanical properties [1]. Abaqus offers a viable and cost-effective substitute for experimental testing, enabling process and design optimization to forecast the behavior of AL5052-H32 in industries such as chemical processing, automotive, and marine applications [2]. Furthermore, although experimental research frequently emphasizes macro-level responses rather than local variations, Abaqus provides intricate stress and strain distributions at the micro-scale, incorporating material models to replicate complex scenarios, thus enhancing understanding, lowering costs, increasing accuracy, and enabling safe testing under extreme conditions [3-4]. The simulation of AL5052-H32 examines its mechanical behavior under diverse loading conditions, emphasizing strain rates, temperatures, and thermal conductivity effects [5-6]. It assesses stress-strain predictions, optimizes mesh density and boundary conditions, and evaluates yield and ultimate tensile strengths. Abaqus is a prevalent program used for modelling materials such as AL5052-H32, an aluminum alloy esteemed for its corrosion resistance and mild strength, delivering precise evaluations for intricate loading conditions [7]. Abaqus' methodology for modelling AL5052-H32 includes interconnected simulations, nonlinear models, customization, and in-software post-processing, effectively capturing mechanical and thermal effects, precisely depicting strain-hardening and anisotropy, and obviating the need for additional tools [8-11]. Current Abaqus material models for AL5052-H32 have limits in accuracy under certain loading circumstances, as shown in the research "Modelling the Flow Behavior of Aluminum Alloy 5052," which offers suggestions for improvement [12]. The study investigates the mechanical and thermal characteristics of lightweight alloys to improve their applications in the automotive, marine, and aerospace sectors, therefore impacting material selection and facilitating the creation of corrosion-resistant components [13]. The modelling technique integrates tensile, compression, flexural, and thermal testing to depict mechanical and thermal behaviors, therefore connecting design and production, enhancing failure predictions, and elevating industry standards via precise material models [14].

Attallaha et al. (2013) discovered that incorporating industrial waste silica gel particles and carbon fiber into unsaturated polyester resin enhanced its flexural strength, modulus, and compressive strength. Murugesan et al. (2011) investigated the cold rolling process of symmetrical short U-profile sheets using sophisticated techniques. Chaimongkon et al. (2013) investigated the influence of material anisotropy on the forming limits of AA5052-H32 aluminium sheets. Song et al. (2013) investigated the plastic deformation properties of 5052 aluminium alloy, while Fang et al. (2013) identified strain rate sensitivity and uniform ductile fracture mechanisms. Kumar and Singh (2013) performed a computer investigation of deformation behaviour.

Dhaliwal and Newaz (2013) investigated Al/CFRP hybrid composites, emphasising stiffness, weight reduction, load-bearing capacity, and failure mechanisms. Chen et al. (2009) investigated the stress-strain characteristics of extruded AA6xxx and AA7xxx aluminium alloys, offering an in-depth comprehension of their dynamic mechanical properties in T6 temper. Manganiello et al. (2006) examined the inelastic flexural behaviour of aluminium alloy structures, establishing ductility for more straightforward plastic analysis methods. Feng et al. (2017) examined the flexural performance of 30 concrete-filled aluminium alloy thin-walled tubes, yielding significant data on square and rectangular hollow sections for composite construction applications.

Ma et al. (2013) performed uniaxial tensile testing on AA5052-O, analyzing stress-strain correlations while integrating drag stress, mobile and forest dislocations, and dynamic strain ageing into the Arrhenius model. A unique constitutive model was created based on physics, which captures strain-rate sensitivity as the strain rate increases. Khodaei et al. (2013) used a finite element model to replicate the high-velocity impact of projectiles on aluminium honeycomb structures filled with polyurethane foam. Noh et al. (2013) investigated the mechanical properties of rivets and connecting sheets by guided tensile and compression testing. Park et al. (2013) examined the influence of heat loss on weldability in the μ-Friction Stir Welding method using three backing-plate materials. Abuzaid et al. (2013) examined the physical characteristics of AA 5083 aluminium alloy plates at different temperatures, revealing a 25% reduction in elastic modulus and a 40% reduction in yield strength during quasi-static isothermal tensile testing. Ouyang et al. (2013) investigated the mechanical clinching process of Al5052-H32/polyoxymethylene hybrid structures, demonstrating that the mechanical clinching approach

yields a robust connection. Wang et al. (2013) investigated the influence of graphene on the mechanical behaviour, tensile and flexural properties, and electrochemical performance of cross-layered glass-reinforced aluminium (GLARE) laminates.

Abuzaid et al. (2013) examined the elastic characteristics of AA 5083 aluminium alloy plates over different temperatures, revealing a 40% reduction in elastic modulus and yield strength at 300°C. Dasa et al. (2013) investigated the influence of heat treatment, SiCp content, and particle size on compressive strength, impact strength, flexural strength, and maximum deflection in three-point bending tests. Papabathina et al. (2013) emphasised the promise of Al6061/SiC/graphite hybrid composites for industrial use. SAGAR et al. (2013) investigated the compression, flexural, and wear characteristics of Al6082-T6 using a Zwick/Roell 250 kN electromechanical universal testing apparatus. Prakash et al. (2013) examined the flow stress characteristics of magnesium alloy AZ81 subjected to tensile, compressive, and flexural forces. Murugesan et al. (2013) investigated the geometric profile in the cold roll-forming of symmetrical short U-shape sheets. Zhang and Li (2013) examined the influence of alloying components, secondary phases, and temperature on the thermal conductivity of aluminium alloys. Mohammed (2013) examined the tensile, compressive, and flexural properties of kenaf and flax composites, demonstrating their applicability in the automotive and aerospace industries.

Jin et al. (2013) validated a measurement approach using ABAQUS software, finding that the patterns in the deformation curves were in strong agreement. The finite element method (FEM) indicated a slightly elevated buckling temperature compared to experimental data, indicating that thermal buckling may be investigated in engineering structures such as nuclear facilities, oil refineries, and aerospace applications. Zhao et al. (2013) examined the deformation and failure characteristics of 5052 aluminium alloy using the ABAQUS/Explicit finite element solver platform. Urooj et al. (2013) examined the properties of steel and aluminium using ABAQUS-CAE software, investigating variations in load and temperature across different geometries. K.M. Zhao and J.K. Lee (2001) formulated stress-strain curves for plasticity models and forecasted spring-back angles using ABAQUS/Standard. Krishna et al. (2013) conducted impact and compression-after-impact (CAI) analyses using ABAQUS/Explicit and ABAQUS/Standard solvers. Feih et al. (2013) created a finite element model to forecast deformations, the onset of

plastic collapse, and eventual failure of aluminium specimens in flames, using heat flux levels from various fire types. Kim Yeow et al. observed remarkable concordance in their analysis of the thermal performance of pouch, prismatic, and cylindrical Li-ion battery cells and modules under diverse cooling conditions and loads.

The size of grains significantly influences deformation behaviour, with many slip events leading to increased local hardening and premature plastic deformation near grain boundaries. Mathier et al. (2008) examined heat flow, mushy alloy rheology, liquid feeding, and porosity development, finding that at around 92% solid fraction, the solid-skeleton behaviour transitions from granular to coalesced. Zhu and Young (2013) contrasted the direct strength method with the bending strengths of aluminium alloy square hollow section beams, whereas Aldajah et al. (2013) used a finite element model (FEM) to replicate four-point bending tests on three specimens. Verma et al. (2020) examined the energy absorption capacity, yield stress, and densification strain values of aluminium foams by finite element modelling. Honeycomb sandwich structures provide superior stiffness-to-weight and strength-to-weight ratios, making them ideal for significant structural aerospace components such as ailerons, elevators and rudders.

Matli et al. (2018) examined the use of high-energy ball milling, vacuum sintering, and microwave sintering techniques to produce aluminium metal matrix composites reinforced with copper particles. Venkatesh and Rao (2018) examined copper hybrid metal matrix composites (MMCs) reinforced with graphite and alumina, whereas Arunprasath et al. (2021) discovered that composites based on copper slag had superior mechanical strength. Czerwinski (2020) investigated thermal stability, while Orbulov et al. (2020), Bendarma et al. (2013), and Rao et al. (2013) contributed more research.

1.2 Aluminum alloy (Al5052-H32) Material.

AL5052-H32 vies for the best aluminum alloy among the entire 5000 series as it has an excellent resistance to corrosion especially in a marine environment. AL5052-H32 may be used in applications that require a reasonable amount of stress as this alloy has good weldability and has an average strength. The combination of these letters and numbers ‘H32’ represent the temper of the alloy which means that this alloy has undergone cold working and heat treatment in order to reach a half-hard condition. The applications of this aluminum alloy are used commonly in the automotive industry, aerospace, and marine including but not limited to fuel tanks, pressure vessels, and exterior panels. This alloy has an excellent formability and allow for good machining as well.

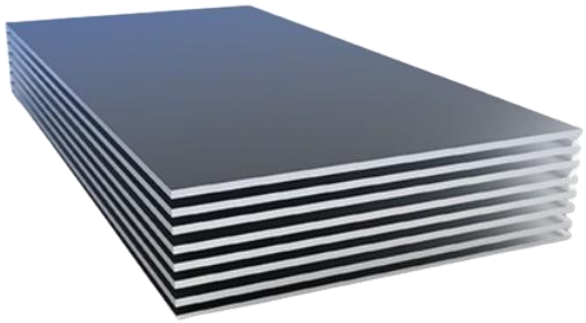


Fig 1: Aluminum alloy (Al5052-H32) plate.

1.3 Material Characteristics.

It is a medium strength alloy and is majorly used where higher strength is desired along with good formability applications. The alloy is very weldable, hence suitable for various manufacturing processes. AL5052-H32 has good fatigue resistance and is non-heat treatable; the strengthening of this alloy depends upon cold working. It is lightweight, easily machinable, and resistant to stress corrosion cracking, finding wide application in industries.

Table 1: The chemical composition of Al5052-H32

Constituent	Percentage (%)
Manganese (Mn)	0.0 - 0.10
Iron (Fe)	0.0 - 0.40
Copper (Cu)	0.0 - 0.10
Magnesium (Mg)	2.20 - 2.80
Silicon (Si)	0.0 - 0.25
Zinc (Zn)	0.0 - 0.10
Chromium (Cr)	0.15 - 0.35
Others (Total)	0.0 - 0.15
Other (Each)	0.0 - 0.05
Aluminum (Al)	Balance

The advantages of AL5052-H32 aluminum alloy:

- Excellent Corrosion Resistance: Good resistance, especially for saltwater environments and sea-coast atmospheres.
- Good Weldability: Welds satisfactorily with conventional techniques; very suitable for applications that are subjected to manufacturing or repairs.
- Medium Strength: Offers an excellent strength-to-weight ratio for structural uses and will not overweight structures.
- Light Weight: Useful in transportation systems to save weight in such industries as automotive and aerospace industries to improve fuel efficiency and overall performance.
- Good formability: Which can easily be formed into complex designs.
- Fatigue Resistance: Cyclic loading does not much affect the performance of the material, hence it's durable in dynamic applications; and
- Non-Heat Treatable: It strengthens by cold working thus it is easier to process without special heat treatment.

Applications:

i. Marine Industry: It is utilized in making the hull of the boat, fuel tanks, and other marine parts that are exposed to saltwater environments.
ii. Automotive Industry: It is applied in making fuel tanks, body panels, and other components which require lightweight and durable materials.
iii. Aerospace: Fuel tanks, fuselage panels, structural parts-all those places where weight reduction and resistance to corrosion are decisive.
iv. Construction: Architectural, roofing, and siding applications require resistance against weathering.
v. Pressure Vessels: Pressure tanks, storage tanks for liquids, and chemical processing equipment are all applications where this alloy can be used due to its corrosion-resistant properties.
vi. Electrical Enclosures: Housings of electrical equipment and panels that require strength and resistance to environmental factors.

1.4 Objectives

The objectives of this experiment as follows;

i. to Compare the Simulation with the Experimental data to validate accuracy of simulated model,
ii. to Simulate the Mechanical (Tensile, Flexural, Compression) of Al5052-H32 using Abaqus,
iii. to Conduct details analysis of Thermal behaviour of Al5052-H32,

CHAPTER 2: MATERIALS AND METHODOLOGY

2.1 Materials

The aluminum alloy (Al5052-H32) was investigation on the deformation behaviors under various test with different conditions.

2.2: Material Properties

The material used for simulations is Aluminum 5052-H32, an alloy known for its high strength-to-weight ratio and corrosion resistance. The material properties were obtained from experimental data and literature. Key parameters include:

Table 2: Mechanical Properties of Aluminum 5052-H32.

Mechanical Property	Value
Young's Modulus:	70300 MPa
Poisson's Ratio	0.33
Yield Stress:	175 MPa
Ultimate Tensile Strength:	300 MPa
Hardness Brinell	61 HB

Table 3: Physical Properties of Aluminum 5052-H32.

Physical Property	Value
Density	2.68 g/cm³
Melting Point	605 °C
Thermal Expansion	23.7 x10^-6 /K
Thermal Conductivity	138 W/m. K
Electrical Resistivity	0.0495 x10^-6 Ω .m

2.3: CAD Modeling and Meshing

Specimens for tensile, compressive, and flexural tests were modeled following ASTM standards. The geometries were created in Abaqus/CAE as follows:

2.3.1 Tensile Test

Cylindrical rods of 12 mm diameter of the aluminium alloy Al5052-H32 is used to designed for tensile test. Where gauge length of 40 mm and middle cross-sectional area specified a diameter of 10 mm, and 6 mm thickness.

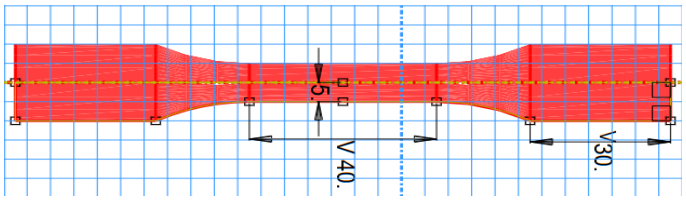


Fig 2: Dimension of Tensile test specimen (mm).

2.3.2 Compression Test

The cylindrical specimens for the compression test are designed with two different Length-to-Diameter (L/D) ratios. The first specimen has a Length-to-Diameter ratio of 0.5, with a diameter of 12 mm and a length of 6 mm. The second specimen has a Length-to-Diameter ratio of 1.5, with a diameter of 12 mm and a length of 18 mm.

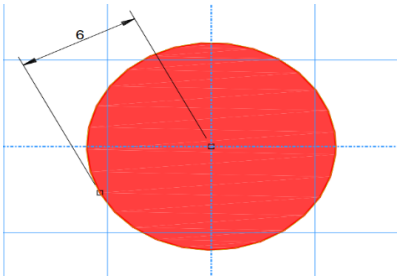


Fig 3: Dimension of Compression test specimen (mm).

2.3.3 Flexural Test

For the flexural tests, flat specimens with a thickness of 6 mm and a width of 10 mm are used. There only span length 120 is considered for the simulation.

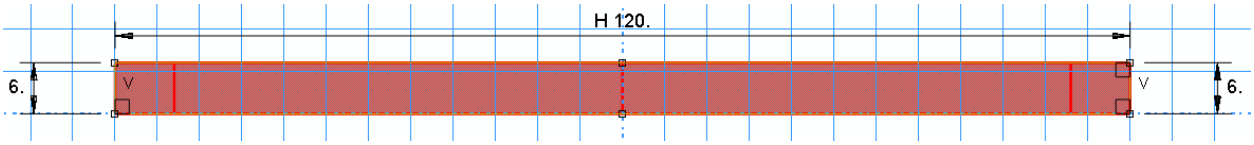


Fig 4: Dimension of Flexural test specimen (mm).

2.3.4 Thermal Test

For the thermal simulation test, a square plate with a length and width of 1 mm, and a thickness of 6 mm, is used.

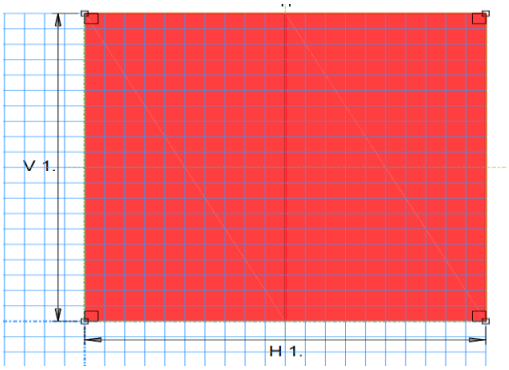


Fig 5: Dimension of Thermal test specimen (mm).

A structured mesh was applied using quadratic tetrahedral elements (C3D10) for Tensile, Compression and Flexural Test. But quad mesh used for only Thermal test. A mesh sensitivity analysis was conducted to ensure convergence, balancing computational efficiency and accuracy.

2.4: Boundary Conditions and Loading

Boundary conditions were applied to replicate experimental setups:

2.4.1 Tensile Test

The model is subjected to fixed constraints at one end, where the displacement at that end is completely restricted in all degrees of freedom. This means that the translational displacements (in the X, Y, and Z directions) and rotational degrees of freedom are all set to zero at the fixed end, ensuring that this end remains stationary during the simulation. Apply a force on one opposite end of the specimen.

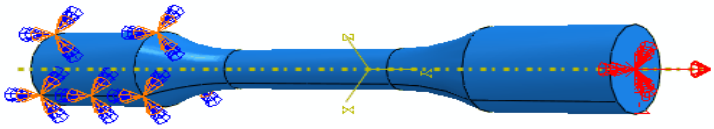


Fig 6: Boundary condition of Tensile test.

2.4.2 Compression Test

The setup for a compression test involves the anchoring of the bottom surface of the specimen, which constrains all possible degree of freedom-translations and rotations-on that surface, keeping it stationery. Subsequently, a compressive load is applied at the top surface of the specimen. Because the load would be distributed uniformly on the area of the surface, simulation of compressive forces acting on the material is achieved.

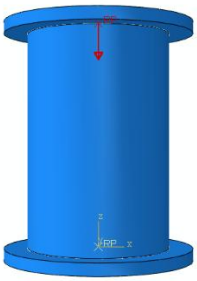


Fig 7: Boundary condition of Compression test.

2.4.3 Flexural Test

The boundary condition set up for a flexural test on a specimen with two simple supports is to take two supports that are rollers or pinned at each end of the specimen. These kinds of supports, however, permit only no vertical displacements and thus allow rotation, implying one can freely rotate at supports and is constrained in the no vertical movement at the supports.

The load normally comes at the center of the span or usually vertically, simulating the central loading condition. Thus, such a setup allows for a bending moment across the length of the specimen to be established and analyzed due to applied velocity with regard to the deflection and stress distribution.

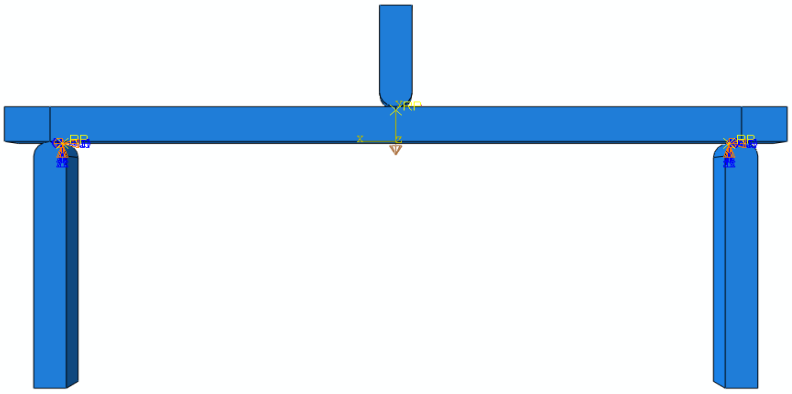
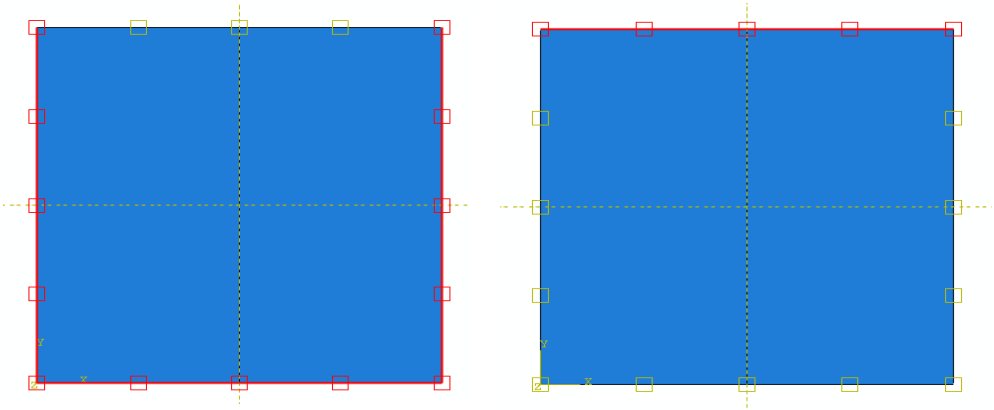


Fig 8: Boundary condition of Flexural test.

2.4.4 Thermal Test

The boundary conditions comprise a uniform temperature of the surroundings in thermal test, that is, the room temperature on the bottom and side surfaces, effectively clamping those surfaces at the constant temperature in the whole course of the simulation, a heat treatment on the top surface, that is, the top side of the specimen will be at an elevated or variable temperature to simulate such cases as exposure to heating or processing. All the simulations were performed under quasi-static conditions with strain rates matching experimental tests.



(a) room temperature side on surfaces

(b) heat treatment on the top surface

Fig 9: Boundary condition Thermal test.

2.5: Validation with Experimental Results

The simulated stress-strain curves were compared to experimental data to validate the numerical model. Key metrics such as yield stress, ultimate tensile strength, and deformation patterns were analyzed. The percentage error between experimental and simulated results was calculated to ensure accuracy.

2.6: Mesh Dependency Analysis

		Tensile Test	Compression Test	Flexural Test
Martial Characteristics	**Diameter (mm)**	12	12	
	Length (mm)	40	6 and 18	120
	Thickness (mm)	6	6	6
	Width (mm)			10
FEA Results	**Maximum Deviation from Experimental (%)**	1.85	2.51	1.99
	Solver Time (hrs.)	2-4	2-3	2-3

Table 4 : Showing the mesh result

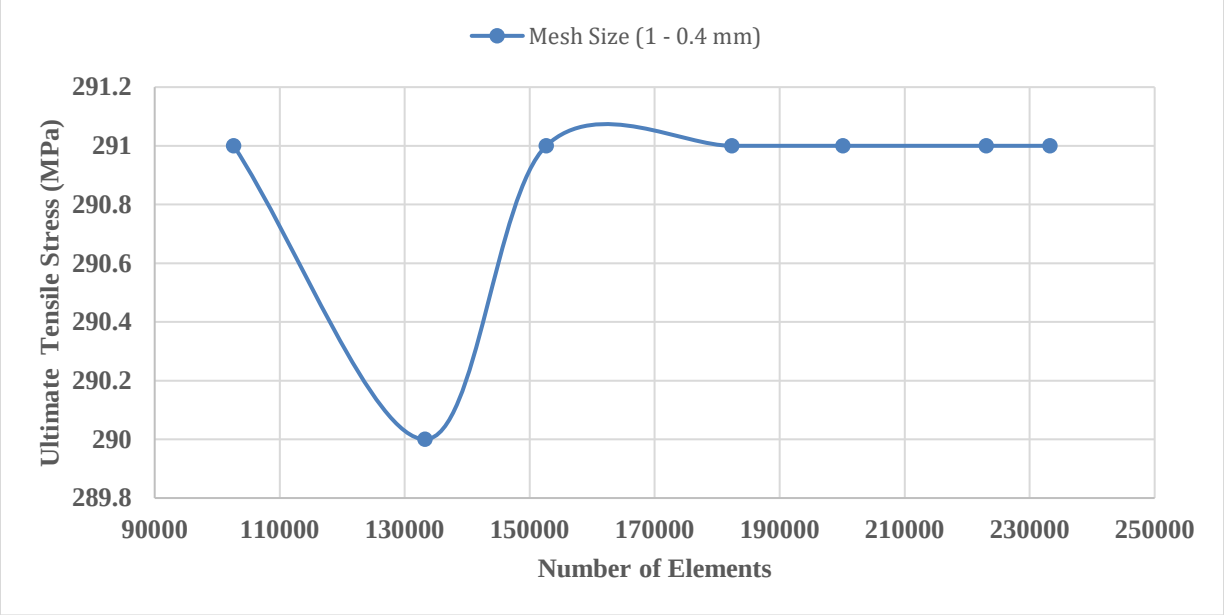


Fig 10: Mesh Dependency of Tensile test

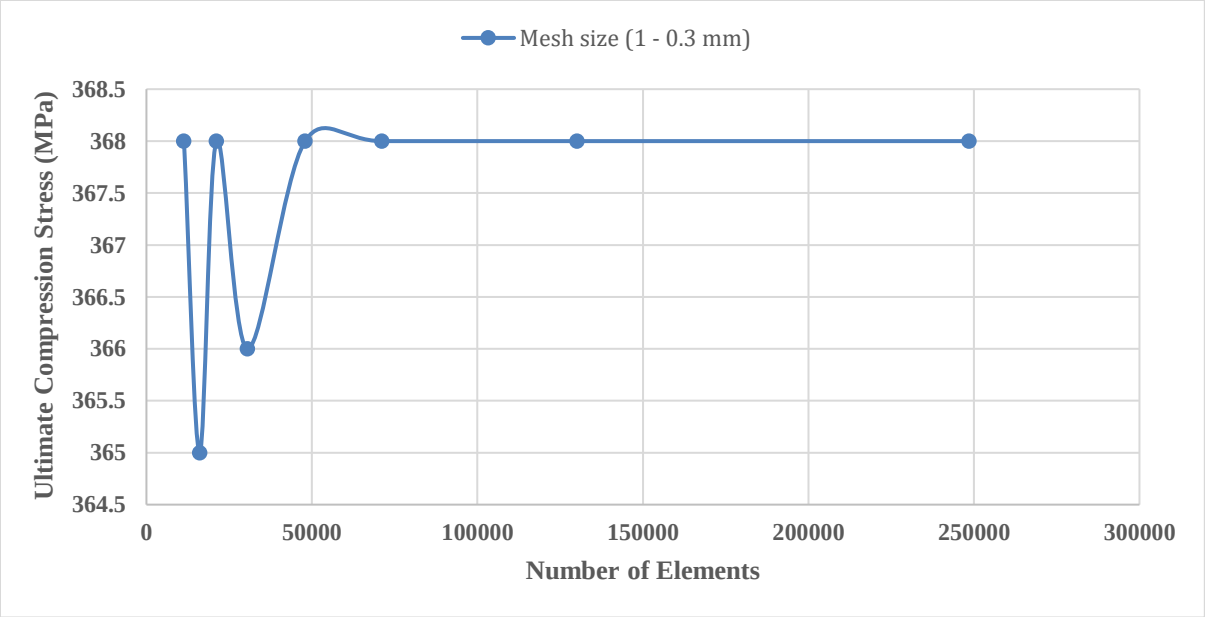


Fig 11: Mesh Dependency of Compression test

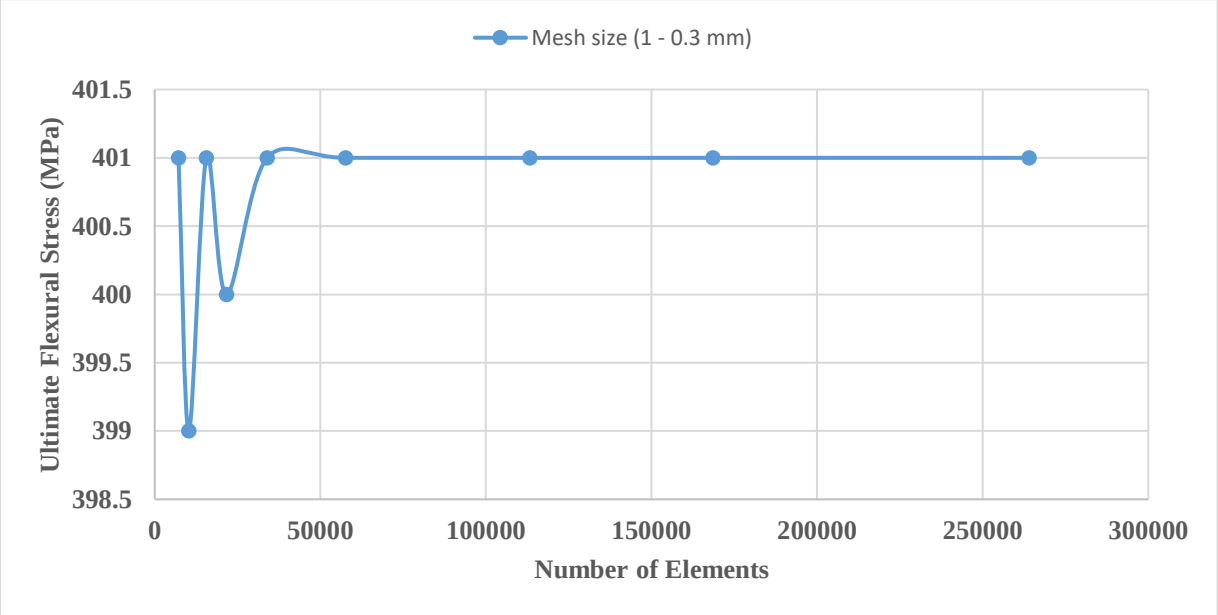


Fig 12: Mesh Dependency of flexural test

2.7: Software and Computational Details

All simulations were performed in Abaqus/CAE 2024 using the implicit solver. The computational setup included:

- Hardware: Intel(R) Core (™) i5-8265U with 8 GB RAM.
- Solver: Dynamic, Explicit for Tensile test and Compression, Flexural tests are Static, General. Finally Thermal is Steady-State
- Simulation Time: Approximately 1–2 hours per test.

2.8: Challenges and Assumptions

The following assumptions were made in the simulations:

- Isotropic material behavior was assumed for Aluminum 5052-H32.
- Strain-rate dependence was neglected in the initial simulations and later introduced for parametric studies.
- Frictional effects in contact surfaces (e.g., during compression) were considered negligible.

CHAPTER 3: RESULT AND DISCUSSION

3.1 Tensile Test Behavior

The tensile tests were simulated using Abaqus software configured in the shape of dog bones. All experiments were performed at ambient temperature. The dimensions used for the simulation models were modified to align with the experimental findings **Fig. 11**.

The simulation test's stress-strain curve begins at a low value and progressively ascends at a strain rate of (0.001 s^{-1}), demonstrating ductile behaviour characterised by considerable plastic deformation, with the final tensile stress recorded at 291 MPa, whereas the actual test at the same strain rate yielded (300 ± 2) MPa. The minimal variation is calculated ($\frac{4}{291} \times 100$) = 1.37% between the simulation and experimental test. The engineering stress-strain curves from the simulation are compared with the experimental engineering stress-strain curves in **Fig. 10 (a and b)** at various strain rates, while the findings from both the experimental and simulation studies of the alloy are shown in **Table 4.**

Conversely, a moderate strain rate of (0.1 s^{-1}) in the simulation test exhibits a steeper starting slope, signifying more stiffness and yielding at elevated stress levels compared to the low strain rate, which aligns closely with experimental observations, differing by just 1.38%. The curves at high strain rates (1000 s^{-1} and 1300 s^{-1}) are much steeper, suggesting that the material exhibits increased brittleness at elevated strain rates and stress levels, with ultimate tensile stresses of 216 and 226 MPa, respectively. In contrast, practical tests at a strain rate of (1000 s^{-1}) demonstrate that material behavior transitions to a more brittle response, with higher stress levels exhibiting a marginal variation of nearly 2% relative to the simulation value.

The modelling and experimental graphs exhibit comparable trends and data, indicating that the mechanical characteristics of Al5052-H32 fluctuate with strain rate. The material exhibits greater ductility at reduced strain rates and lower stress levels. At elevated rates, it becomes rigid and moderate, requiring more stress to attain the same strain. This indicates a strong correlation between the patterns seen in simulation and experimental data, validating that the simulations will effectively reflect actual behaviour. In fine, Comparison of tensile test results image of Simulation and Experimental for Aluminum5052-H32 under various strain rate showed in **Fig.12 (a and b).**

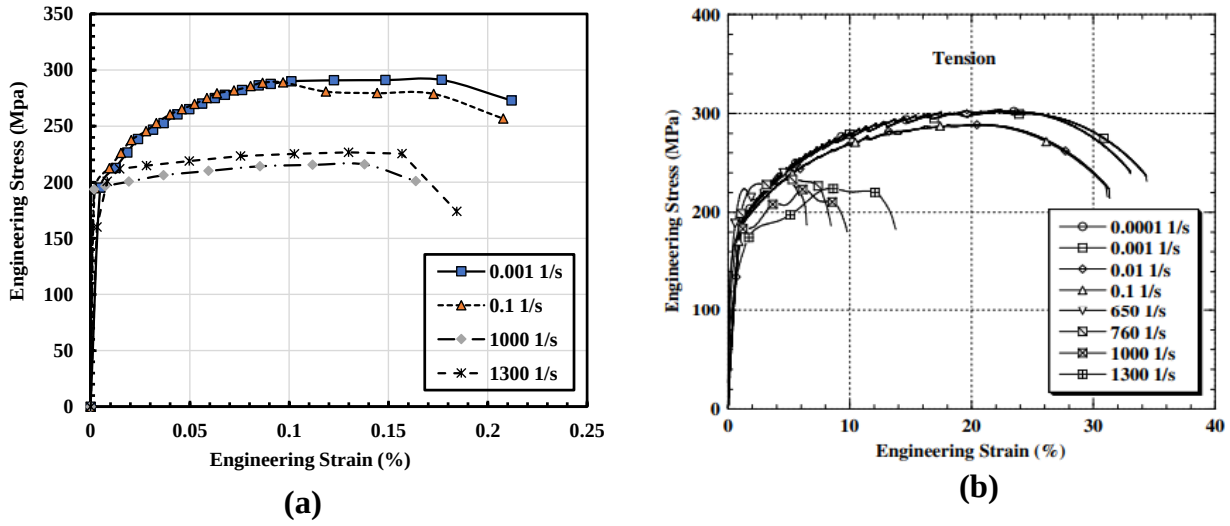
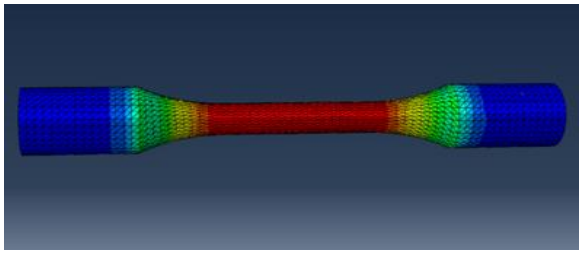


Fig 13: Comparison at different strain rates of (a) Simulation engineering stress versus engineering strain; and (b) Experimental stress versus engineering strain curves.

	Experimental Engineering stress–strain curves			**Simulation stress–strain curves**	
Strain rate (s−1)	Temperature (°C)	Yield stress (MPa)	UTS (MPa)	Yield stress (MPa)	UTS (MPa)
0.001	25	181 ± 1	300 ± 2	180	291
0.1	25	175 ± 1	286 ± 2	175	289
1,000	25	185 ± 3	225 ± 2	180	216
1,300	25	180 ± 1	226 ± 2	180	226

Table 5: Comparison between Experimental & Simulation results of the tensile tests at room temperatures under various strain rate.

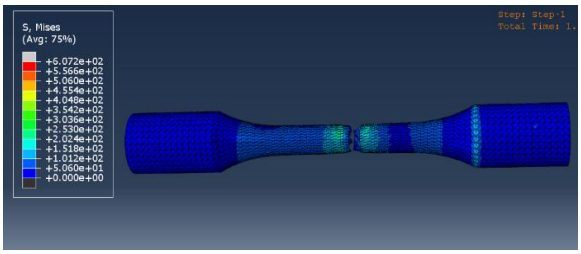


(a)



(b)

Fig 14: Showing specimen for tensile test (a) simulation (b) experimental.



(a): Simulation image showing deformation



(**b)** Deformation of experimental image



(c): Electromechanical universal testing machine under quasi-static tensile loads.

Fig 15: Comparison of tensile test results image (a and b) of Simulation and Experimental for Aluminum5052-H32 under. (c) is experimental methods.

3:2 Compressive Test Behaviour

In this investigation, the simulation results of the stress-strain curve responses for the compressive behaviour of Al5052-H32 alloy were assessed at room temperature at two distinct aspect ratios (0.5 and 1.5). The engineering stress–strain curves from the simulation over the specified range of strain rates and aspect ratios (L/D) are juxtaposed with experimental data in **Fig. 13(a, b, c, d)**, and both experimental and simulation outcomes are detailed in **Table 5**. Utilising a specimen with a length-to-diameter (L/D) ratio of 0.5. The simulation outcomes for the ultimate compressive stress of Aluminium 5052-H32 alloy at varying strain rates closely align with experimental data. At a strain rate of 1200 s^{-1}, both the modelling and experimental findings indicate 251 MPa, with no error. At 1600 s^{-1}, the simulation precisely corresponds with the experimental value of 350 MPa, demonstrating no divergence. At 2500 s^{-1}, the simulation forecasts a final stress of 368 MPa, but the real value is 371 ± 4 MPa, resulting in a negligible error of 2.17%, which falls within the experimental uncertainty range.

Conversely, with the L/D ratio of 1.5 and applied low strain rates (450 s^{-1}), the stress-strain curve shows a progressive rise in stress, with the final compressive stress reaching 199 MPa, which aligns with the actual test at the same strain rate. This indicates ductile behaviour characterised by substantial plastic deformation and reduced rigidity. and the strain rate escalates to 700 s^{-1} in the simulation, the first slope of the curve becomes more pronounced, and the final stress attains 239 MPa. In the experimental scenario, the ultimate stress for this strain rate was 242 ± 3 MPa. Consequently, the calculation yields $\left(\frac{6}{239} \times 100 \right) = 2.51\%$ departure from the experimental test. Both findings indicate enhanced stiffness and a significant rise in yield stress, indicating a shift towards a stronger, less ductile behaviour. At a strain rate of 900 s^{-1}, the ultimate stress is 279 MPa in simulation and 278 ± 3 MPa in experimental results. Consequently, the curve becomes steeper, demonstrating a distinct strain rate sensitivity and a shift towards brittle behaviour at high strain rate circumstances, with no further deviations seen.

Overall, while both L/D ratios demonstrate strong concordance between simulation and experimental outcomes at elevated strain rates, the L/D ratio of 0.5 generally provides more consistency in accuracy over the entire strain rate spectrum. This indicates that shorter specimens may provide more dependable simulations and improved alignment with experimental outcomes, especially in high strain rate compression testing. The findings confirm the precision and reliability

of the simulation model, showing its ability to consistently forecast the material's behaviour under different strain rates. This establishes a robust basis for practical applications and more research into the high-strain-rate behaviour of Aluminium 5052-H32 alloy. Finally, all simulation results have shown in **Fig.14 (a, b, c, d, e, f).**

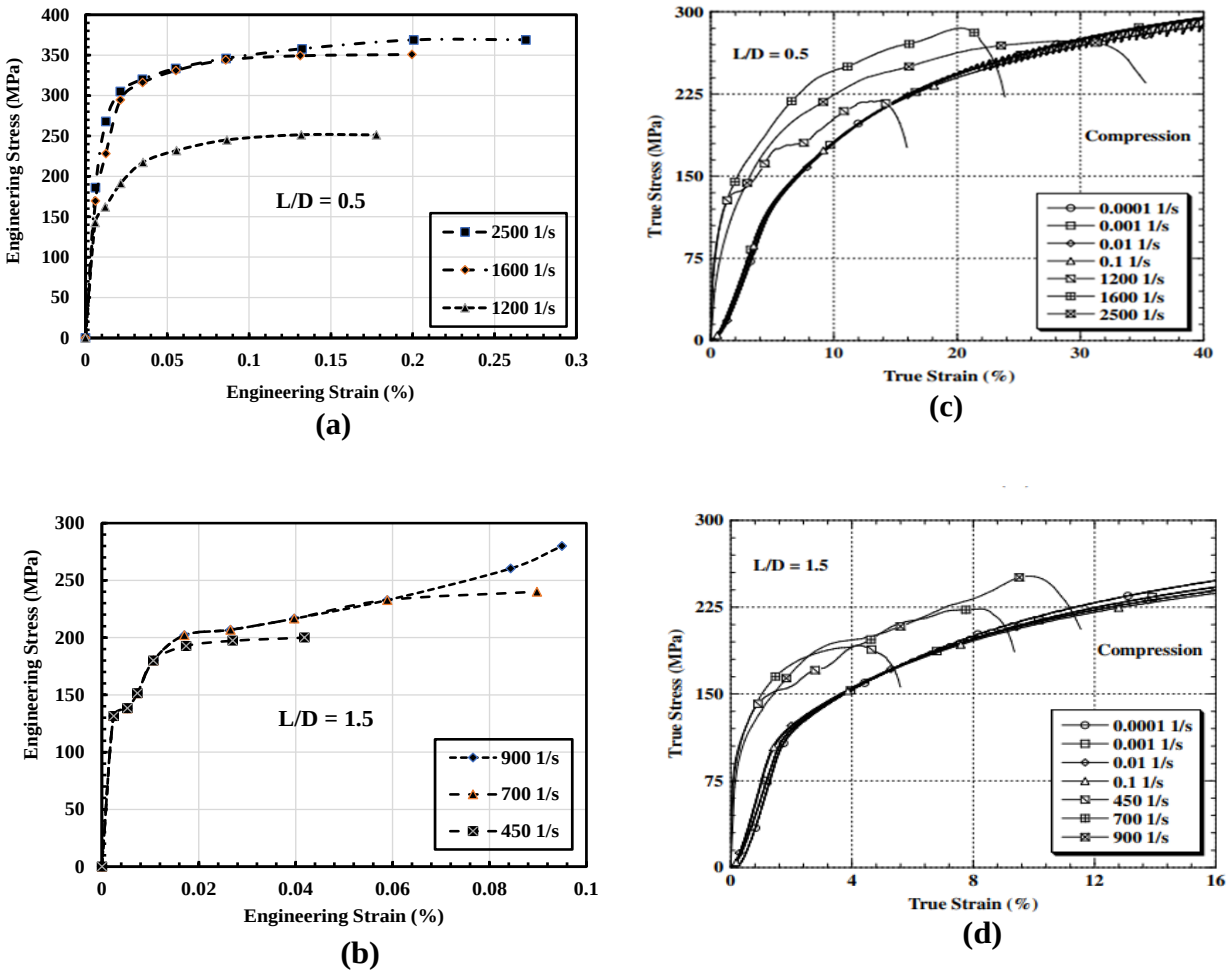
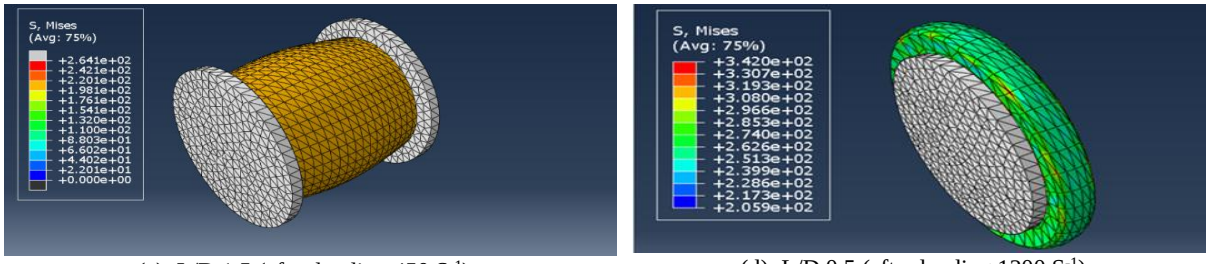


Fig 16: Comparison at different strain rates of compression test where (a), (b) simulation engineering stress versus engineering strain; and (c), (d) experimental true stress versus true strain curves.

	Experimental Engineering stress–strain curves			Simulation stress–strain curves	
Aspect ratio	Strain rate (s−1)	Yield stress (MPa)	Ultimate compressive stress (MPa)	Yield stress (MPa)	Ultimate compressive stress (MPa)
L/D = 1.5	450	124 ± 1	201 ± 2	124	199
	700	130 ± 1	242 ± 3	130	239
	900	128 ± 4	278 ± 3	130	279
L/D = 0.5	1,200	138 ± 2	251 ± 3	140	251
	1,600	140 ± 2	350 ± 4	140	350
	2,500	156 ± 2	371 ± 4	155	368

Table 6: Comparison between Experimental & Simulation results of the Compression tests at room temperatures under various strain rate.



(a): L/D 1.5 (after loading 450 S^{-1}) (d): L/D 0.5 (after loading 1200 S^{-1})

Fig 17: The figure shows Simulation results of Aluminum5052-H32 for compression tests at different strain rates.



(a): Simulation specimen for compression test. (b): Electromechanical universal testing machine for Compression test.

Fig 18: The figure shows Simulation and Experimental test technique.

3:3 Flexural Test Behavior

The simulation results acquired from flexural three-point bending tests are analyzed. **Fig. 16 (a and b)** compares the simulation engineering stress-strain curves with the experimental engineering flexure stress-strain curves at various crosshead speeds (10–200 mm/min) for a span length of 120 mm, while the corresponding experimental and simulation data are detailed in **Table 6.**

At a crosshead speed of 10 mm/min, the modelling and experimental data exhibit similar patterns, with minor discrepancies in the final stress values. In the simulation, the stress-strain curve begins at a minimal stress level, progressively escalating with strain. At a rate of 10 mm/min, the simulation forecasts an ultimate stress of 401 MPa, but the actual data indicates 412 ± 4 MPa, yielding a variance of roughly $\left(\frac{8}{401} \times 100\right)$= 2.%. Both graphs exhibit similar tendencies, with the simulation somewhat underestimating the final stress, perhaps attributable to minor modelling assumptions or experimental variables. This signifies that Aluminium 5052-H32 has rate-sensitive ductility, requiring more stress to get equivalent strain under accelerated loading conditions. The tight correlation further strengthens the metal's reliable and uniform reaction, crucial for applications necessitating exact mechanical performance at comparable strain rates. At a rate of 100 mm/min, both simulation and experimental data show a robust connection in stress-strain behaviour, with the simulation forecasting a final stress of 401 MPa at an engineering strain of 0.035, nearly matching the actual result of 401 ± 1 MPa. The simulation curve has a steeper beginning slope relative to 10 mm/min, signifying increased stiffness and expedited yielding, which aligns with the experimental data that similarly demonstrates a greater final stress at this strain rate. This demonstrates the rate-sensitive characteristics of Aluminium 5052-H32, whereby increased crosshead speeds result in higher stress levels for same strain.

At a rate of 200 mm/min, the simulation forecasts a maximum stress of 399 MPa at an engineering strain of 0.03, but the actual data indicates 398 ± 1 MPa. The disparity between the two is just 2%, signifying exceptional concordance. Both curves exhibit a brittle reaction at this elevated crosshead speed, necessitating more stress to get the same strain. This behaviour exemplifies rate sensitivity, whereby the metal's strength escalates with rapid loading, but its ductility diminishes, rendering it more susceptible to brittle failure at elevated strain rates.

The flexural tests indicate that Al5052-H32 displays rate-sensitive elastic-plastic behaviour, characterized by an increase in strength and a decrease in ductility with rising loading rates. The

simulation model aligns well with experimental results, affirming the material's reliable and consistent performance under different loading conditions. There also demonstrate the simulation situation in different perspective in **Fig.17 (a, b and c).**

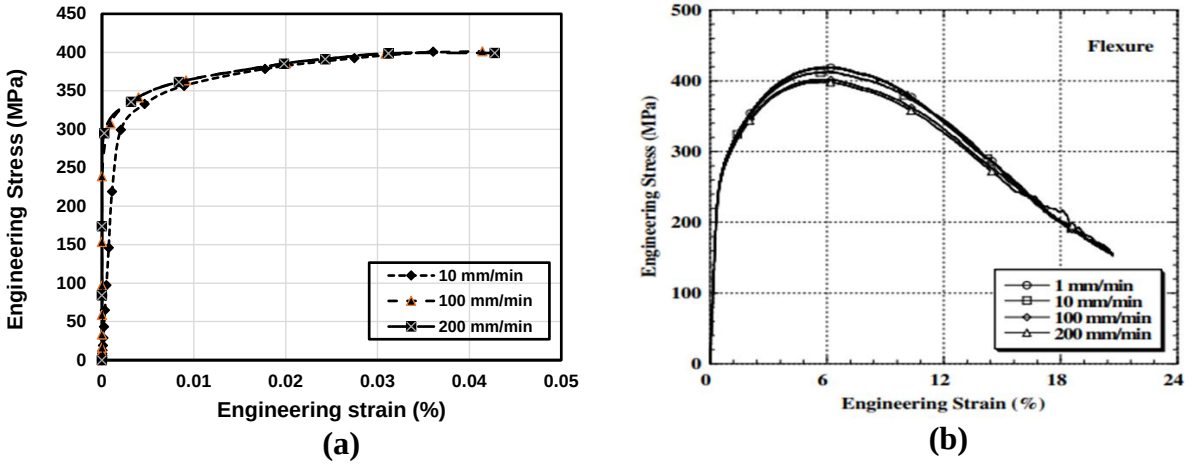
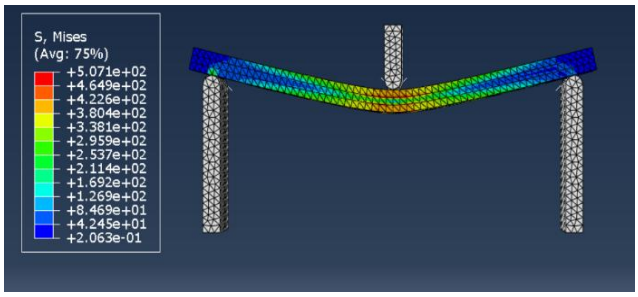


Fig 19: Comparison of flexural stress–strain curves at different crosshead speeds for a span length of 120 mm: (a) simulation engineering stress–strain curves; and (b) experimental engineering stress–strain curves.

Orientation		**Experimental Engineering stress–strain curves**			**Simulation stress–strain curves**	
Flat (loading along thickness)	Span length (mm)	Velocity (mm=min)	Yield stress (MPa)	Ultimate flexural strength (MPa)	Yield stress (MPa)	Ultimate flexural strength (MPa)
	120	10	268 ± 1	412 ± 4	270	401
		100	265 ± 1	401 ± 1	265	401
		200	262 ± 1	398 ± 1	260	399

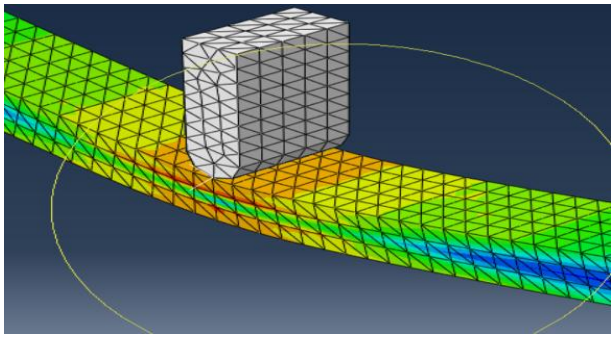
Table 7: Comparison between Experimental & Simulation results of the Flexural tests at room temperatures under various velocity.



(a): Load condition for (10 mm/min) of 120 mm span length of simulation test.



(c): Flexural/three-point bending tests of experimental test.



(b): Showing simulation results



(d): Showing specimen after Experimental test

Fig 20: Showing simulation and Experimental result of Load and Boundary condition for Flexural test of 120 mm span structure.

4:4 Thermal Test Behavior

The aim of this thermal test is to examine the heat flux and temperature distribution in Aluminium 5052-H32 under thermal loading circumstances. The test specifically seeks to acquire the heat flux versus distance and temperature vs distance profiles shown in **Fig. 18 (a, b)**, which will facilitate the understanding of the material's thermal conductivity and its behaviour under temperature gradients. The simulation results of the thermal testing at various temperatures are shown in **Table 7**.

The heat flux distribution across distance at temperatures of 250°C, 350°C, and 450°C demonstrates a distinct pattern of enhanced heat transfer with higher temperature gradients. At 450°C, the heat flux initiates at 20,559.4 W/m² and reaches a maximum of 114,186.6 W/m² over a distance of 1 meter, indicating the highest thermal conduction. At 350°C, the heat flow initiates at 15,721.9 W/m² and ascends to 87,319.2 W/m² along the same trajectory. At 250°C, the initial heat flow is minimal at 10,884.4 W/m², progressively increasing to a peak of 60,451.7 W/m². These findings demonstrate that higher temperatures induce increased heat flow owing to enhanced thermal energy transfer. These qualities are essential in aerospace applications, where aluminium components must effectively dissipate heat under high-temperature conditions, minimizing thermal fatigue and preserving structural integrity.

The temperature distribution across distance under identical thermal conditions (250°C, 350°C, and 450°C) exhibits a slow rise with distance, influenced by thermal conduction. At 450°C, the temperature initiates at 25°C and ascends sharply to the maximum setpoint of 450°C, over a distance of 1 millimeter. At 350°C, the temperature increases from 25°C to 350°C, but at 250°C, it exhibits a similar pattern but culminates at a lower value of 250°C. The pronounced slope at elevated temperatures highlights the material's thermal conductivity efficiency, an essential characteristic for aircraft aluminium alloys. This behaviour guarantees uniform heat distribution across components, averting localised overheating and enhancing thermal management in high-performance aircraft systems. This both test conditional behavior has been shown in **Fig. 19 (a, b, c, d, e. f).**

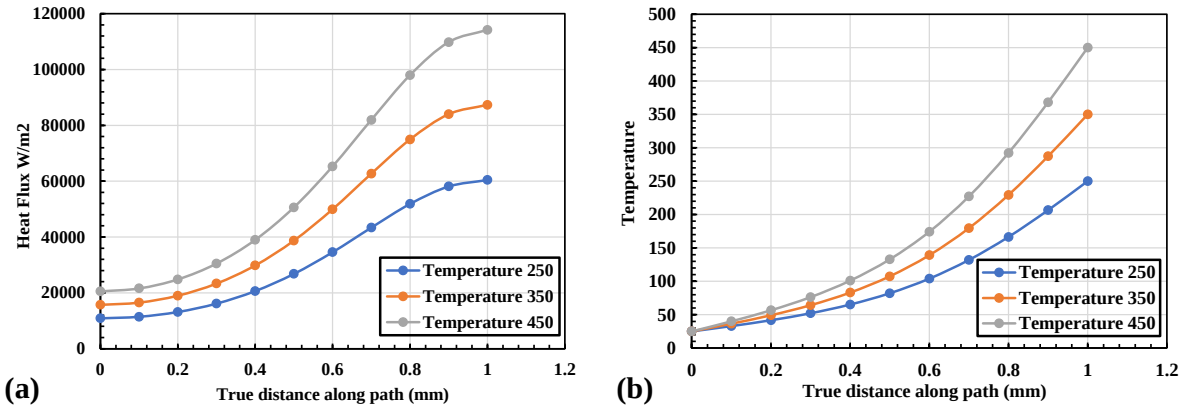
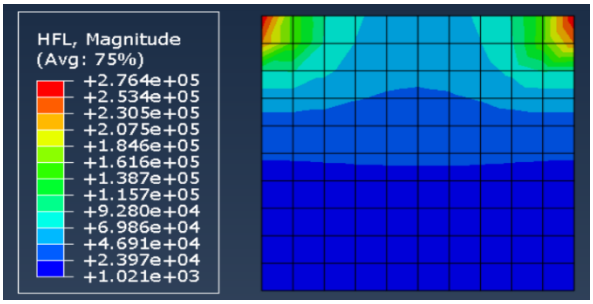


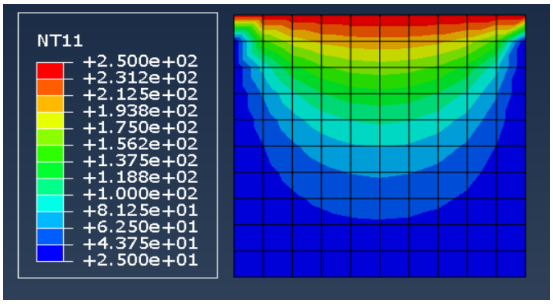
Fig 21: Thermal Test of Aluminum 5052-H32 – (a) Heat Flux vs. True Distance along the Path, and (b) Temperature vs. True Distance along the Path.

Temperature (°C)	True distance along path (mm)	Heat Flux (W/m^2)
250	1	60451
350	1	87319
450	1	114186

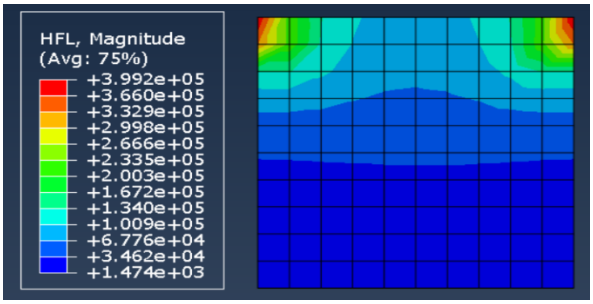
Table 8: Simulation results of the thermal tests at different temperatures.



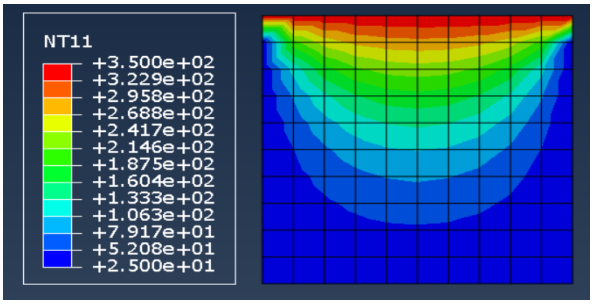
(a) Heat flux vs Distance (Temperature 250ºC)



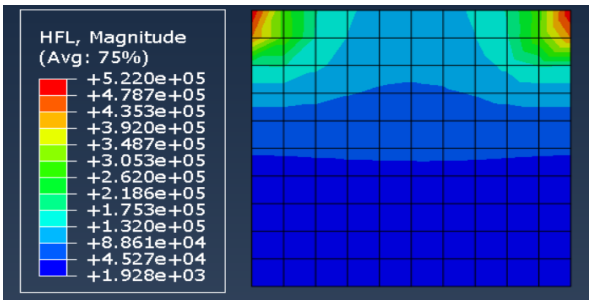
(d) Nodal temperature vs distance (250ºC)



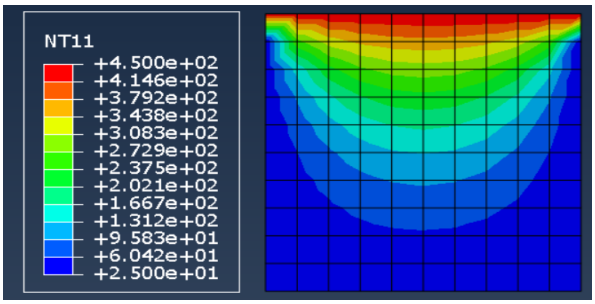
(b) Heat flux vs Distance (Temperature 350ºC)



(e) Nodal temperature vs distance (350ºC)



(c) Heat flux vs Distance (Temperature 350ºC)



(f) Nodal temperature vs distance (450ºC)

Fig 22: Thermal test results under the various temperature (a), (b), and (c) are represented Heat Flux vs. Distance and (d), (e) and (f) Nodal Temperature vs. Distance for Aluminum 5052-H32.

CHAPTER 4: CONCLUSION

4:1 Conclusion

The research focused on investigating the mechanical properties of Aluminium 5052-H32 alloy using finite element simulations under various loading conditions, with the findings aligning closely with experimental data. The simulations effectively captured key characteristics such as yield stress, ultimate strength, deformation, and heat flux behavior, confirming the reliability and precision of the models. In terms of tensile characteristics, the simulations showed a maximum variation of 2% in yield stress and ultimate tensile strength, demonstrating the alloy's excellent ductility and strain hardening. The study also revealed a strong agreement between simulation and experimental results for compressive behavior where maximum deviation 2.51%, that is highest percentage among all the test. validating predictions of deformation and stress distribution under different L/D ratios and strain rates. For flexural behavior, three-point bending models accurately predicted flexural strength and deformation patterns, with discrepancies remaining below 2%, emphasizing the material's strength under bending stresses. Lastly, thermal behavior simulations highlighted the alloy’s ability to manage thermal stresses, with effective predictions of heat flux and temperature distribution. Overall, the research demonstrated that Aluminium 5052-H32 is well-suited for both structural and thermal applications, offering significant insights into material performance without the need for extensive experimental validation.

4.2 Limitations

The investigation of Al5052-H32 alloy and composite sheets has many constraints that may influence the interpretation and applicability of the results.

- Material properties: Isotropic or anisotropic behavior, temperature-dependent material model definitions.
- Plasticity: Non-linear modeling of the stress-strain curve, strain hardening parameters
- Boundary conditions: Impose fixed or symmetry constraints, carefully define contact properties.
- Loading conditions: Impose linear or non-linear loading conditions, time-dependent effects.
- Meshing: Fine enough mesh to capture plasticity and avoid convergence issues.

- Fatigue: Fatigue and damage models in case of cyclic loading.
- Environmental effects: Consider corrosion or oxidation if it is relevant to the application.

These constraints underscore the need for more study including a wider range of materials, enhanced simulations, and diverse experimental circumstances to augment the applicability of the results.

4:3 Recommendations

In considering the results from this investigation, we propose the following recommendations:

- Material Applications: The Aluminum 5052-H32 alloy, characterized by its superior mechanical and thermal qualities, is very appropriate for aerospace, automotive, and structural applications that need high strength-to-weight ratios and corrosion resistance. Future study should include other elements such as strain-rate dependency, anisotropic material behavior, and thermal cycling to improve simulation accuracy.
- Experimental Validation: To enhance the dependability of simulation models, it is important to perform a wider array of experimental testing over extensive temperature ranges and stress circumstances.
- Optimization Studies: Numerical optimization methods must be used to customize alloy characteristics for particular engineering applications, enhancing performance within specified restrictions.
- Collaborative Research: Enhanced cooperation between simulation and experimental researchers may provide a more cohesive knowledge of material behaviors.

These recommendations aim to bridge gaps in simulation fidelity and experimental validation, ultimately advancing material science and engineering applications.

4:4 Future Scopes

- Advanced Material Modeling: Improving material behavior predictions in different scales and considering the effect of microstructure. Establish models for the simulation of material performance at different temperatures, with a particular focus on high-temperature applications.

- Improved Failure and Damage Models: Improved modeling for the prediction of crack initiation and propagation in complex loading. Emphasis on improved fatigue life prediction, together with corrosion-fatigue interaction, with a special focus on the marine environment.
- Additive Manufacturing: Perform simulations for AL5052-H32 in 3D printing, taking into consideration thermal gradients and layer bonding.
- Hybrid Manufacturing: Couple traditional and additive methods in simulations for better design optimization.
- Optimization Techniques: Employ optimization in the design of lightweight structures and achieve a balance in performance, cost, and manufacturability.
- Integration with AI and Software: Leverage AI to accelerate simulations and machine learning for the optimization of material behavior models. CAD/CAE Integration: Integrate design and simulation tools more tightly for enhanced efficiency.
- High-Performance Computing (HPC): HPC will be able to simulate more complex, higher-resolution material behaviors faster.

These developments will improve AL5052-H32 in design, optimization, sustainability, and real-world performance.

4:5 Motivation of the Study

The motivation for simulating an experimental paper is based on several key factors that enhance the value of the study. Simulations allow for reproducibility and validation, ensuring the robustness of the original results under varying conditions. They also enable the exploration of parameters and sensitivity analysis, providing insights into how changes in variables affect outcomes. Additionally, simulations are cost-effective and time-efficient, allowing for extensive testing without the need for physical resources.

By predicting new outcomes, simulations can guide future experiments and highlight areas for further exploration. Lastly, simulations provide an opportunity to improve experimental design, optimizing parameters and refining data collection methods for more accurate results.

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